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# *In Situ* TEM of Instabilities in Capped Liquid Films: Capturing the Early Stages of Morphological Development with Nanosecond-Scale Dynamic TEM

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The thermal stability of thin films is important for performance and reliability of materials for many technical applications. This includes thin liquid films capped by solid films, that (temporarily) occur in devices based on phase change materials (PCMs). PCMs are important for use in optical recording media (CDs, DVDs) and non-volatile resistance-based memory devices, which exploit the distinct optical and electrical properties of the amorphous and crystalline phases. For memory applications, it must be possible to switch between the amorphous and crystalline phases by rapid heating. Heating close to the PCM melting temperature can induce morphological instabilities that could affect device performance and reliability. These instabilities are affected by intrinsic properties such as the interfacial interactions (interfacial energy, van der Waals interactions), atomic transport (viscosity or diffusivity), mechanical properties of the solid film, as well as extrinsic properties such as film thicknesses and stress state in the solid capping film [1, 2].

Thin film dewetting is important for its scientific and technological relevance, but can be difficult to study experimentally. As noted for thin liquid films on solids supports [3], the characteristic amplitude, wave number, and growth rate of a linearized model of dewetting apply to the earliest stages of film breakup, so kinetic data from the early stages of development is necessary for the verification of the model. The early stages of development of morphological instabilities in capped chalcogenide-based phase change materials during laser annealing have been studied with the dynamic TEM (DTEM). The DTEM is a modified conventional TEM that achieves nanosecond-scale time-resolved imaging of irreversible processes in condensed phases with intense photo-emitted electron pulses. The DTEM has been used to study crystallization in PCMs [4, 5], and is used here to image thickness variation developing in amorphous PCM thin films during laser heating. Morphological instabilities were induced with laser pulses in as-deposited amorphous films of GeTe deposited on 20 nm thick amorphous silicon nitride membranes and capped with a thin (<10 nm) oxide layer (eg. silica). The GeTe film thickness was varied from 10 to 40 nm. Bright field images generated from 15-ns electron pulses were recorded. Time-resolved images of the morphological instabilities are shown nanoseconds after laser heating and minutes after in Figure 1. Thicker areas appear darker and thinner areas are lighter. (The morphology of the thickness variations was confirmed, *post mortem,* by imaging focused ion beam (FIB) cross sections (Figure 2).) Comparison of during and after images shows that the characteristic length scale has increased over time. A systematic variation of the characteristic length scale of the sinusoidal instabilities with changing GeTe thickness was observed during the early stages of development, which will be interpreted in terms of dewetting models.

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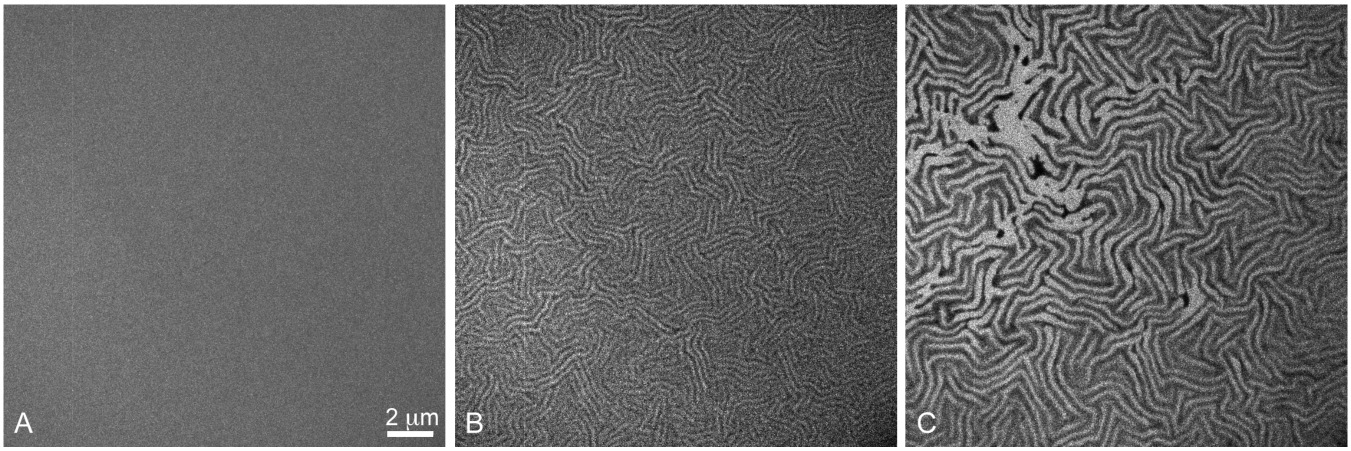


**Figure 1.** Bright field images from 15-ns electron pulses showing the development of laser-induced morphological instabilities and dewetting in GeTe thin film. (A) As-deposited 30nm GeTe film, (B) instabilities developed 500 ns after laser heating, and (C) the same area minutes later. Thicker areas appear darker and thinner areas are lighter. Comparison of during and after images shows that the characteristic length scale of the instabilities has increased over time.

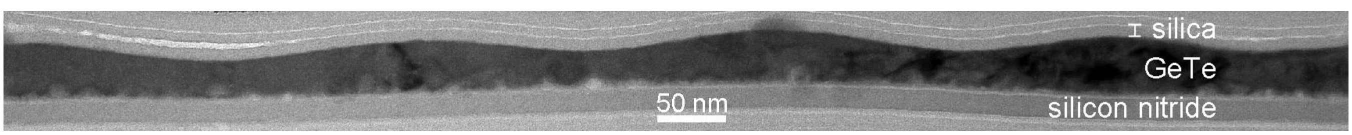


**Figure 2.** Focused ion beam cross section of a GeTe film after laser annealing showing the regular sinusoidal morphology of the instabilities.

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